

A KASSPER Real-Time Signal Processor Testbed

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The Knowledge Aided Sensor Signal Processing and Expert Reasoning (KASSPER) Program is a Defense Advanced Research Projects Agency (DARPA) program which has the goal of improving the performance of Ground Moving Target Indicator (GMTI) radar systems by incorporating external sources of knowledge into the signal processing chain. The KASSPER Real-Time Signal Processor Testbed and its associated Signal Processing Architecture is a prototype radar system scheduling and signal processing framework that has been developed at Massachusetts Institute of Technology Lincoln Laboratory (MIT LL).

A typical scenario in which KASSPER processing could be useful is depicted in Fig. 1. Note that the GMTI clutter environment is heterogeneous (trees, open areas, an urban area, etc). By taking advantage of prior knowledge about this environment (i.e. locations of roads, terrain contours, types of ground cover, etc.), processing algorithms can have an opportunity to improve their performance by avoiding invalid assumptions about the environment.

A top level diagram of the KASSPER architecture is shown in Fig. 2. The components of this architecture that are different from a conventional radar signal processor are the knowledge database, knowledge cache, and the look-ahead scheduler.



Fig. 1. A representative KASSPER problem.

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The knowledge database stores the 'knowledge' that both the signal processing chain and the scheduler need to perform 'intelligent' processing. The knowledge database reformats the knowledge data into a form that is usable by the processing chain during a pre-mission data load. During system operation, the knowledge cache holds the portion of the knowledge store that is within the radar's field of view. The knowledge pre-processing step performs real-time operations such as transformations between geographic coordinates and radar system coordinates.

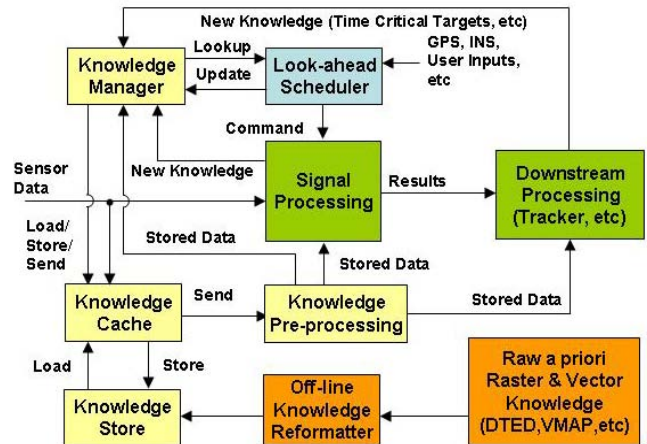


Fig. 2 KASSPER Architecture Block Diagram

An important factor in the performance of knowledge aided signal processing algorithms is that the application of knowledge must be performed locally. This tends to cause the signal processing to be done at a finer grain than is comfortable for achieving good computational efficiency. As an aid to making processor scaling choices for knowledge aided algorithms, signal processing and knowledge database benchmarks have been developed in order to quantify the efficiencies that will actually be achievable.

This talk will discuss the design of the testbed, its architecture; the testbed's software to hardware mapping, knowledge aided processing algorithms, as well as computational performance data that have been collected for important knowledge-aided processing kernels.

A number of topics (such as the look-ahead scheduler) are currently areas of ongoing research. An overview of the potential benefits as well as a vision of how the architecture will incorporate knowledge aided scheduling will be presented.



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Lincoln Laboratory**

28 September 2004

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MIT Lincoln Laboratory



Outline



KASSPER Program Overview

- **KASSPER Processor Testbed**
- **Computational Kernel Benchmarks**
 - **STAP Weight Application**
 - **Knowledge Database Pre-processing**
- **Summary**

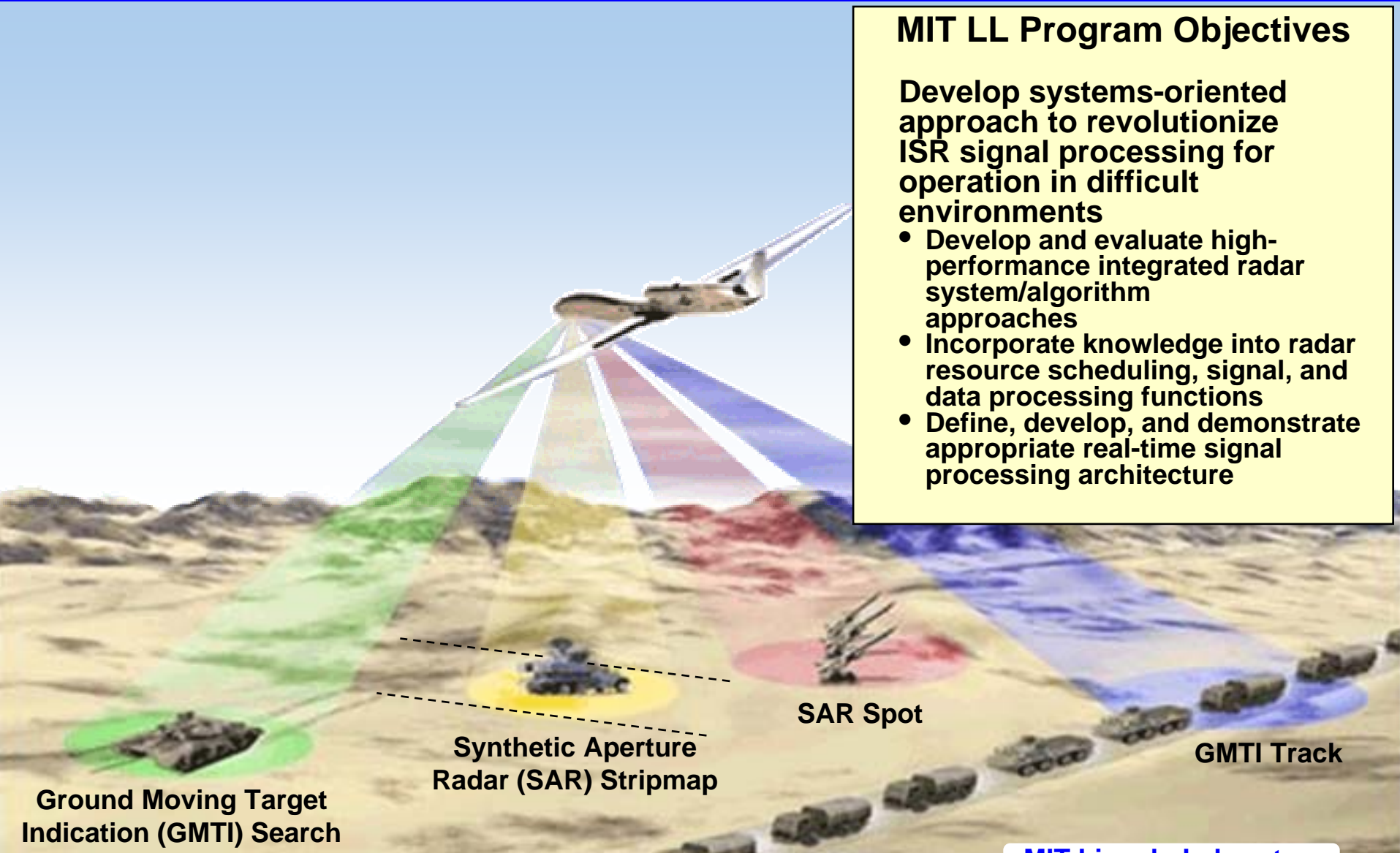


Knowledge-Aided Sensor Signal Processing and Expert Reasoning (KASSPER)

MIT LL Program Objectives

Develop systems-oriented approach to revolutionize ISR signal processing for operation in difficult environments

- Develop and evaluate high-performance integrated radar system/algorithm approaches
- Incorporate knowledge into radar resource scheduling, signal, and data processing functions
- Define, develop, and demonstrate appropriate real-time signal processing architecture



Ground Moving Target
Indication (GMTI) Search

Synthetic Aperture
Radar (SAR) Stripmap

SAR Spot

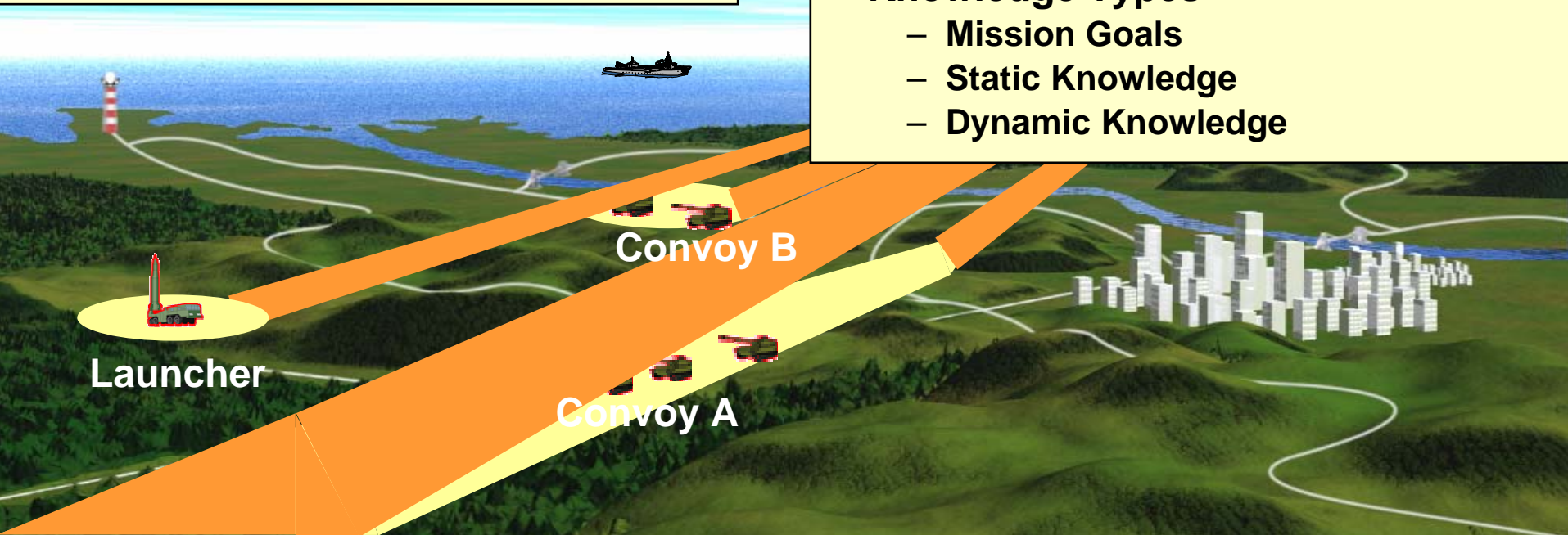
GMTI Track



Representative KASSPER Problem

- **Radar System Challenges**
 - Heterogenous clutter environments
 - Clutter discretizes
 - Dense target environments
- **Results in decreased system performance (e.g. higher Minimum Detectable Velocity, Probability of Detection vs. False Alarm Rate)**

- **KASSPER System Characteristics**
 - Knowledge Processing
 - Knowledge-enabled Algorithms
 - Knowledge Repository
 - Multi-function Radar
 - Multiple Waveforms + Algorithms
 - Intelligent Scheduling
- **Knowledge Types**
 - Mission Goals
 - Static Knowledge
 - Dynamic Knowledge





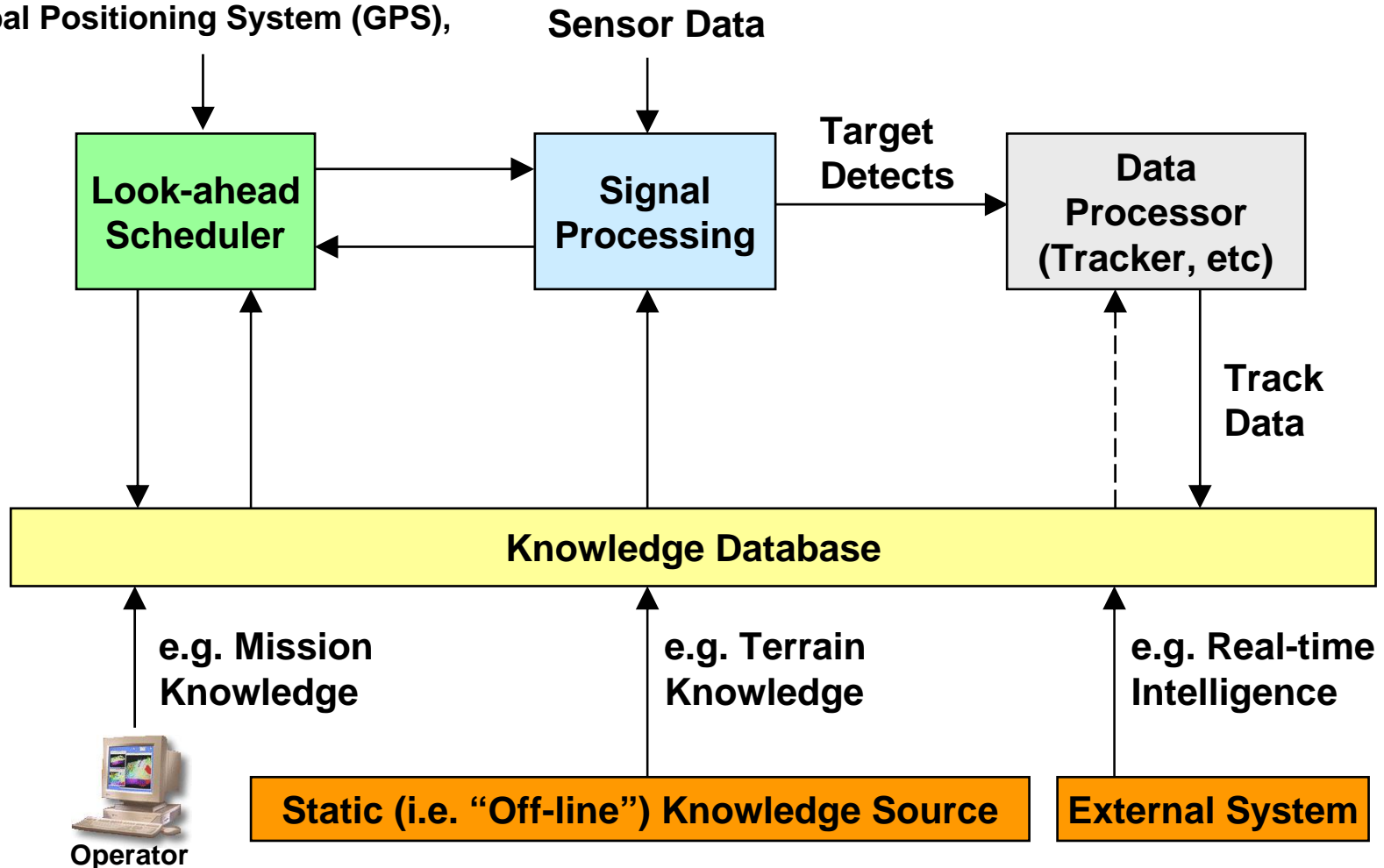
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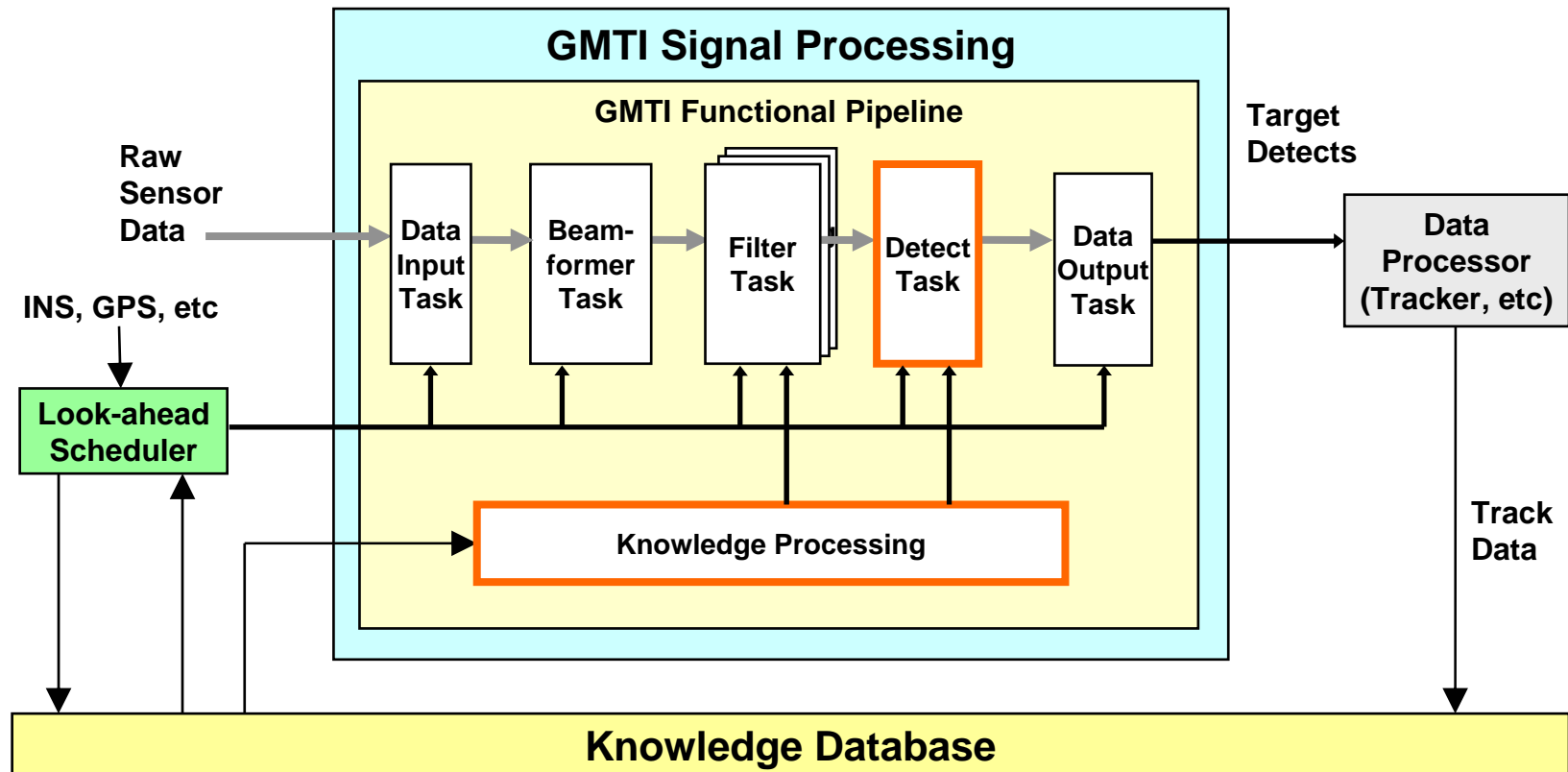
High Level KASSPER Architecture

Inertial Navigation System (INS),
Global Positioning System (GPS),
etc.





Baseline Signal Processing Chain

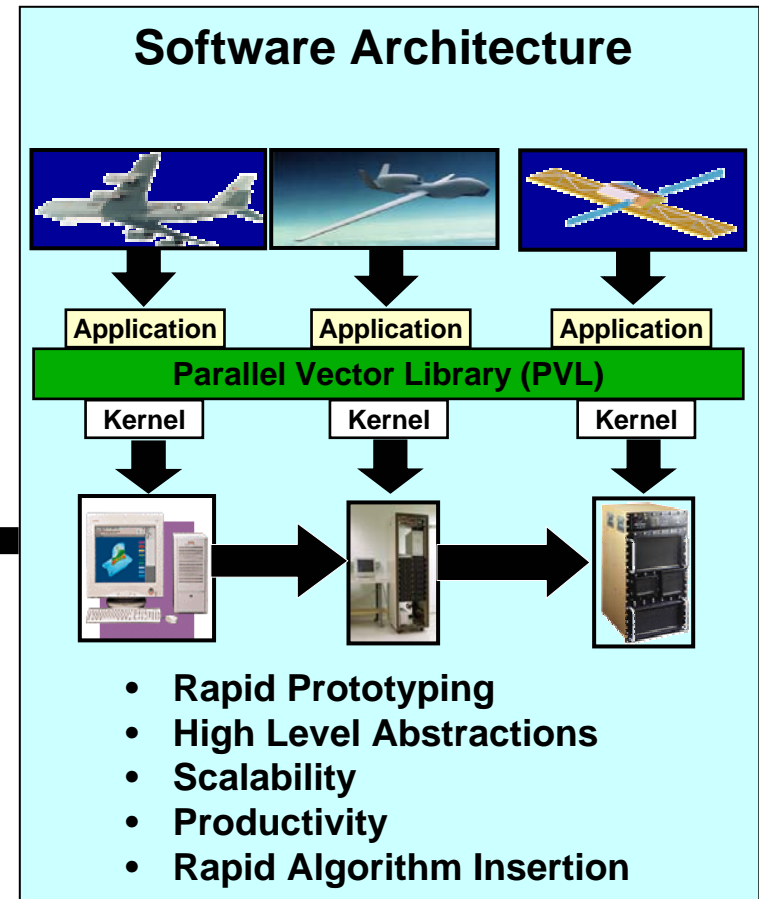
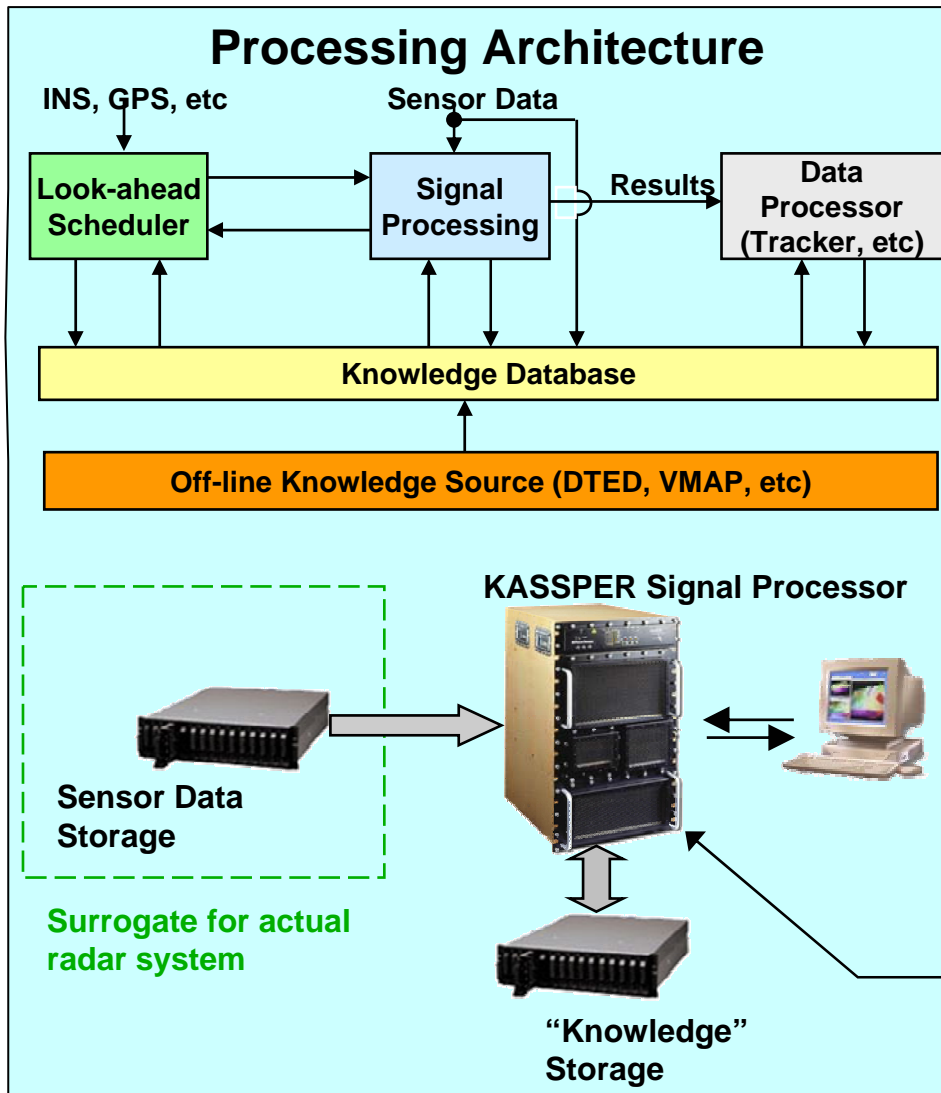


Baseline data cube sizes:

- 3 channels x 131 pulses x 1676 range cells
- 12 channels x 35 pulses x 1666 range cells



KASSPER Real-Time Processor Testbed

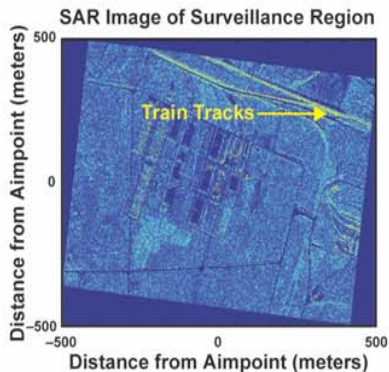
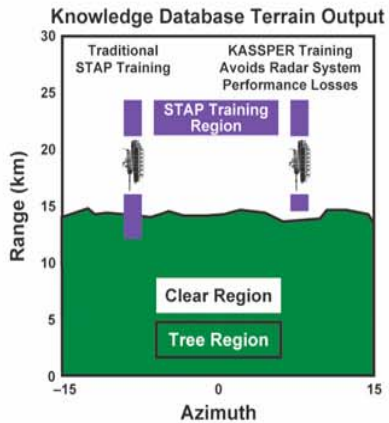


120 PPC G4 CPUs @ 500 MHZ
4 GFlop/Sec/CPU = 480 GFlop/Sec

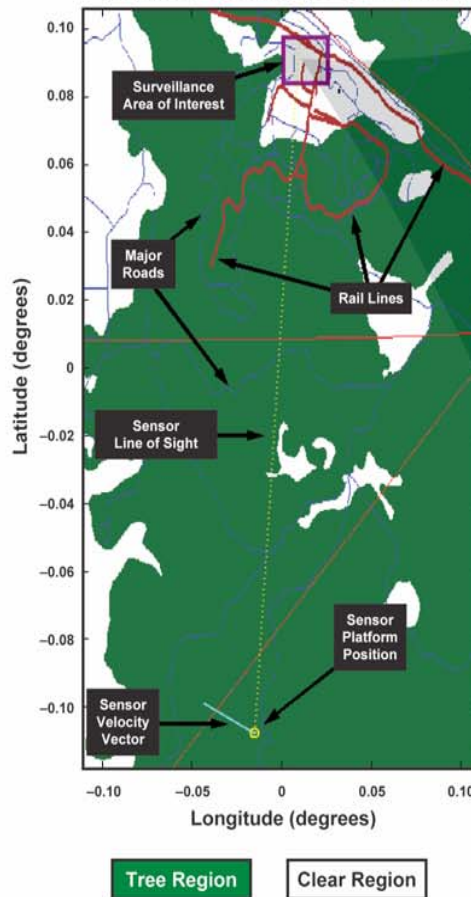


KASSPER Knowledge-Aided Processing Benefits

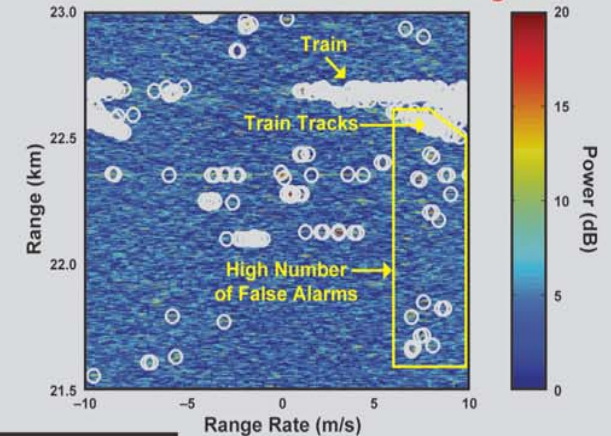
Additional Knowledge Sources for Use in KASSPER Processing



Example Surveillance Scenario

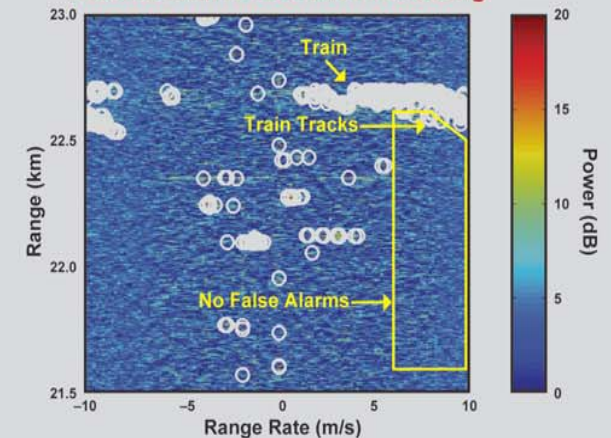


Results Without KASSPER Processing



O Detected Targets

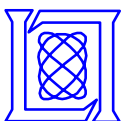
Results With KASSPER Processing



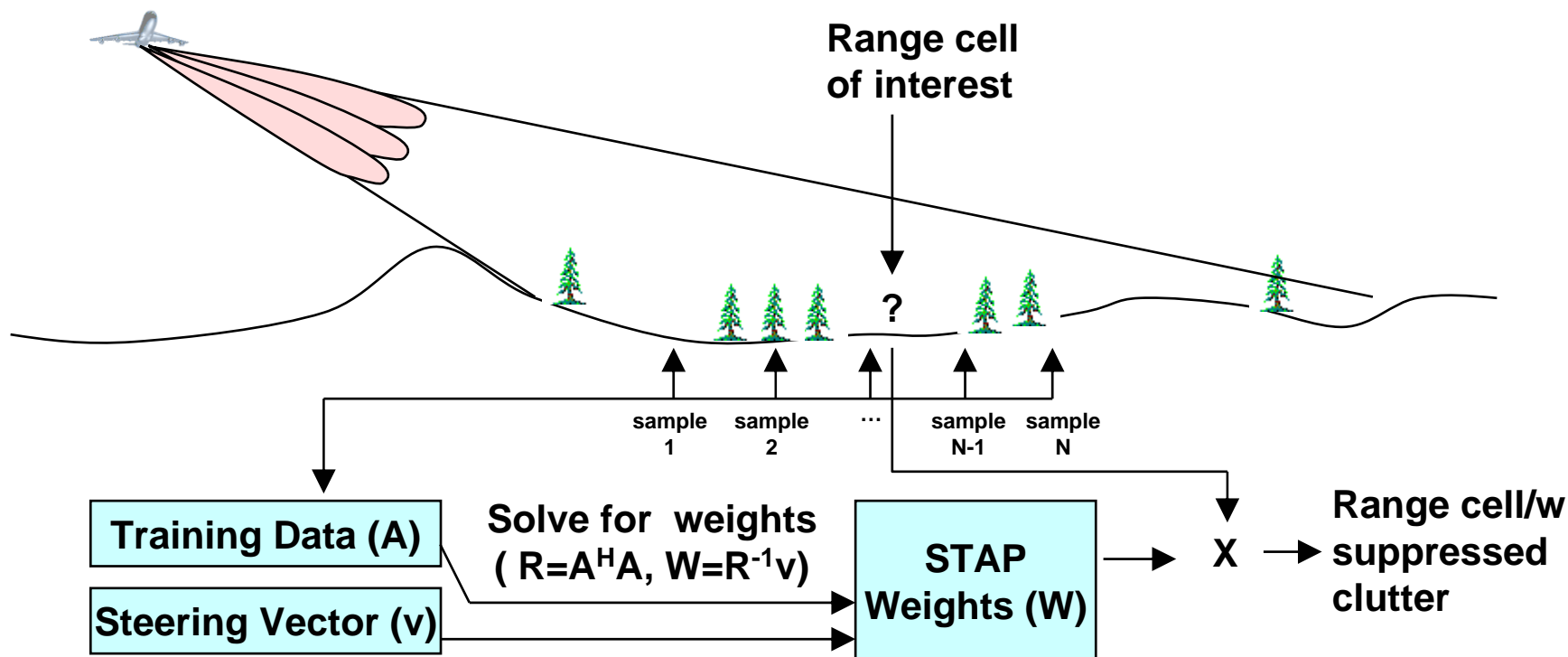


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 - ➔ **– STAP Weight Application**
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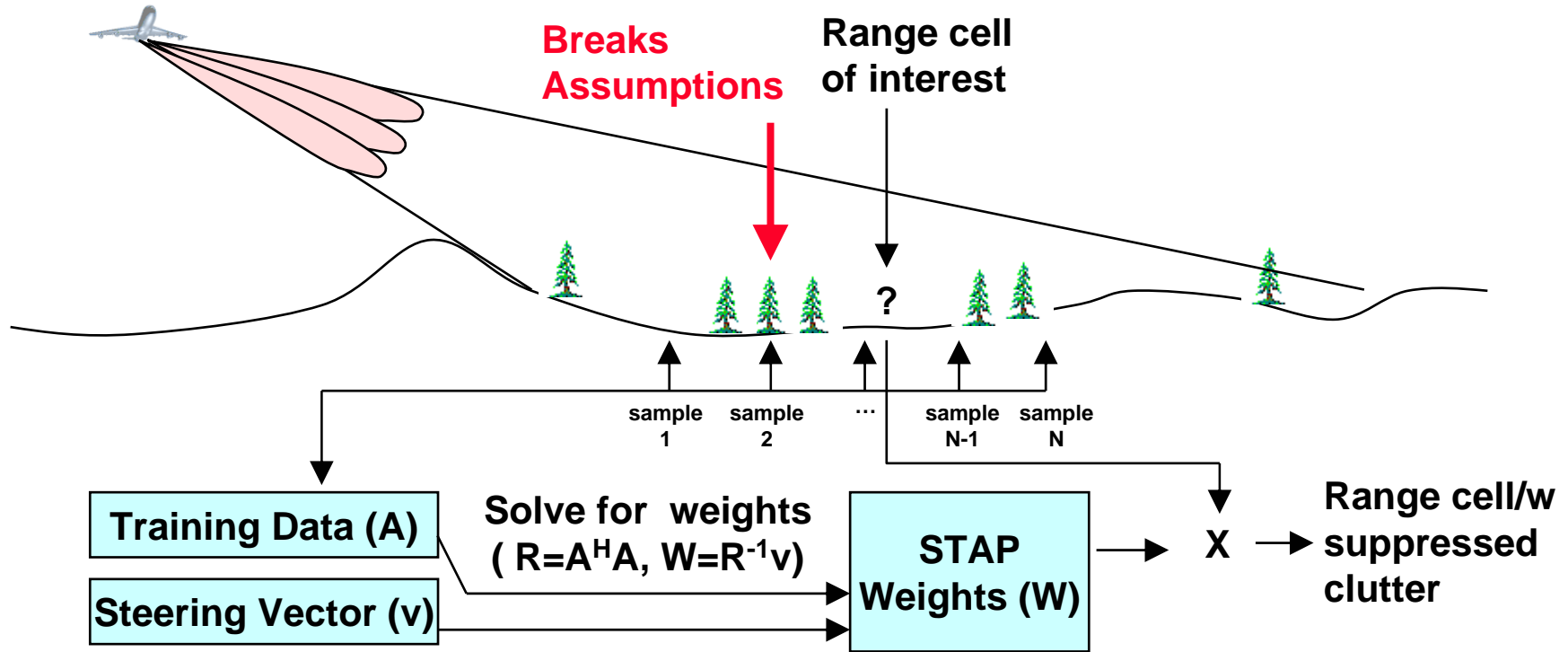
Space Time Adaptive Processing (STAP)



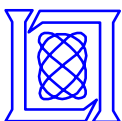
- Training samples are chosen to form an estimate of the background
- Multiplying the STAP Weights by the data at a range cell suppresses features that are similar to the features that were in the training data



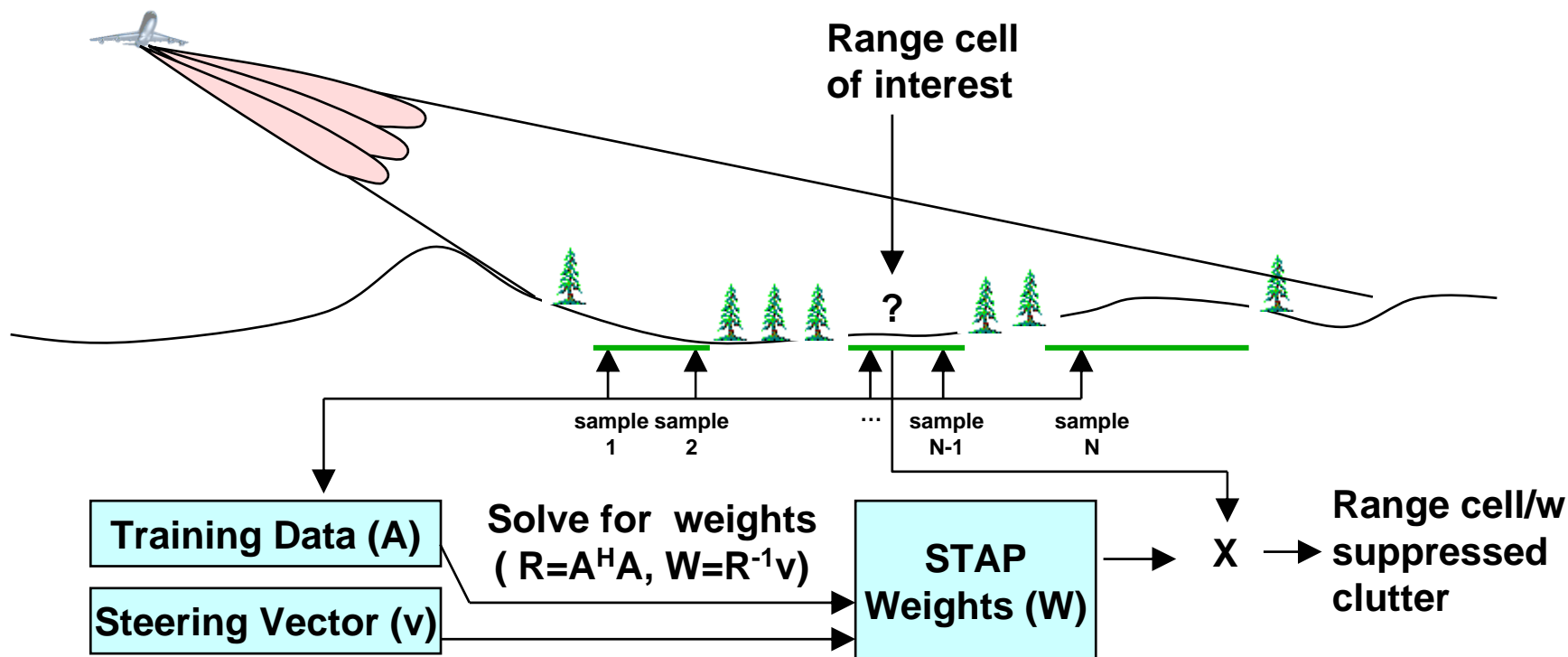
Space Time Adaptive Processing (STAP)



- Simple training selection approaches may lead to degraded performance since the clutter in training set may not match the clutter in the range cell of interest



Space Time Adaptive Processing (STAP)

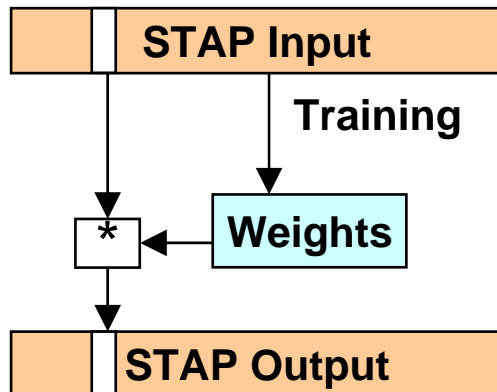


- Use of terrain knowledge to select training samples can mitigate the degradation

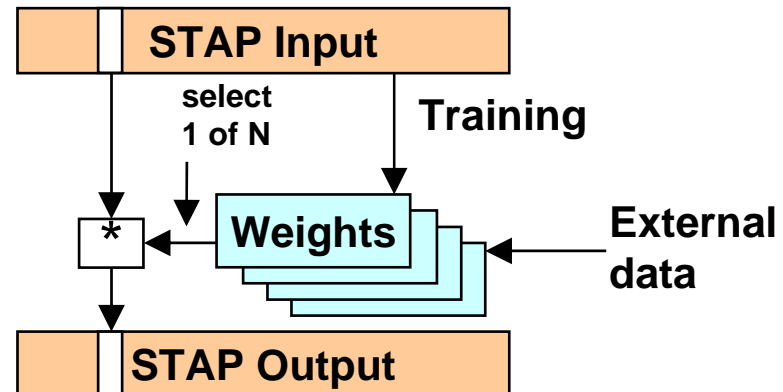


STAP Weights and Knowledge

- STAP weights computed from training samples within a training region
- To improve processor efficiency, many designs apply weights across a swath of range (i.e. matrix multiply)
- With knowledge enhanced STAP techniques, **MUST** assume that adjacent range cells will not use the same weights (i.e. weight selection/computation is data dependant)



Equivalent to Matrix Multiply
since same weights
are used for all columns



Cannot use Matrix Multiply
since the weights applied to
each column are data dependant

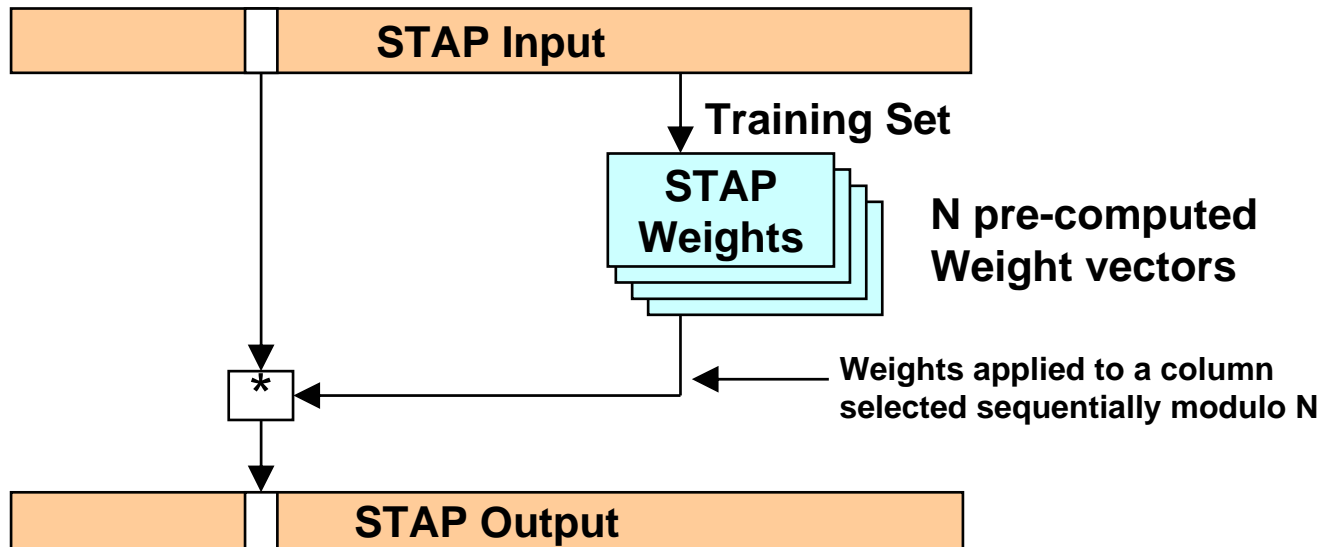


Benchmark Algorithm Overview

Benchmark Reference Algorithm (Single Weight Multiply)

$$\text{STAP Output} = \text{Weights} \times \text{STAP Input}$$

Benchmark Data Dependant Algorithm (Multiple Weight Multiply)

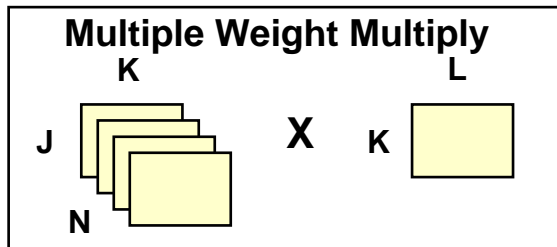
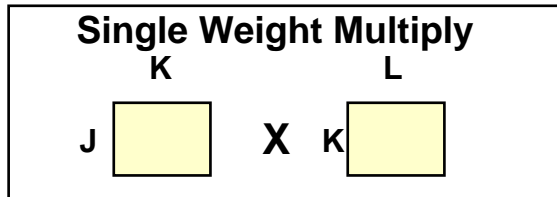


Benchmark's goal is to determine the achievable performance compared to the well-known matrix multiply algorithm.



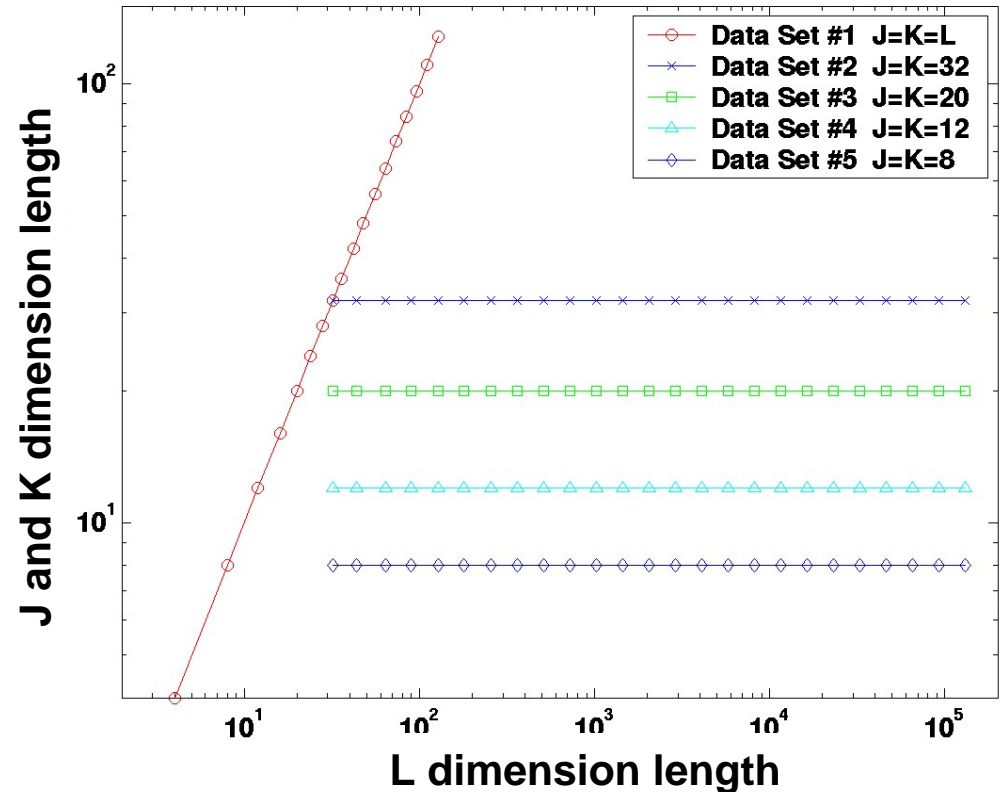
Test Case Overview

Data Set J x K x L



N = # of weight matrices = 10

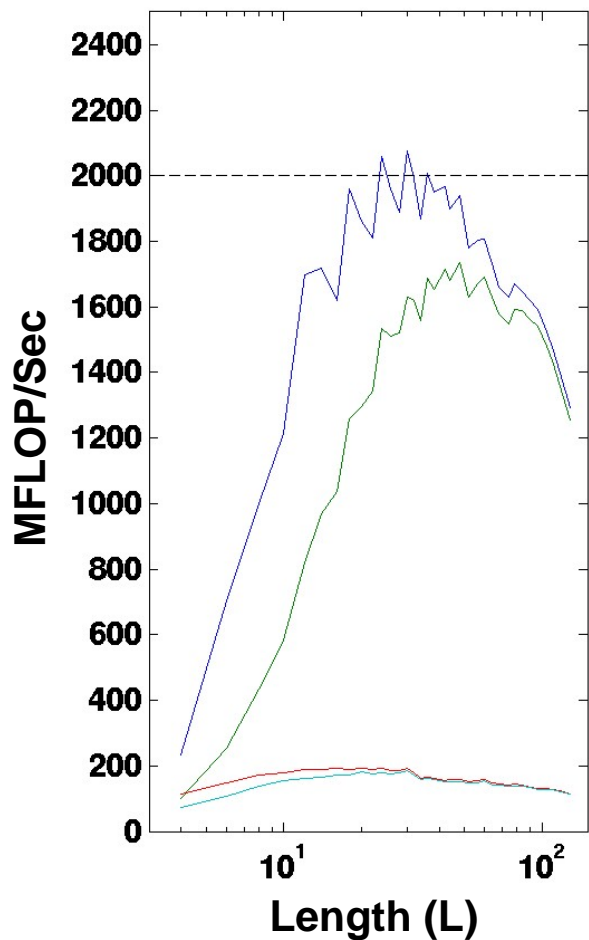
- **Complex Data**
 - Single precision interleaved
- **Two test architectures**
 - PowerPC G4 (500Mhz)
 - Pentium 4 (2.8Ghz)
- **Four test cases**
 - Single weight multiply/wo cache flush
 - Single weight multiply/w cache flush
 - Multiple weight multiply/wo cache flush
 - Multiple weight multiply/w cache flush



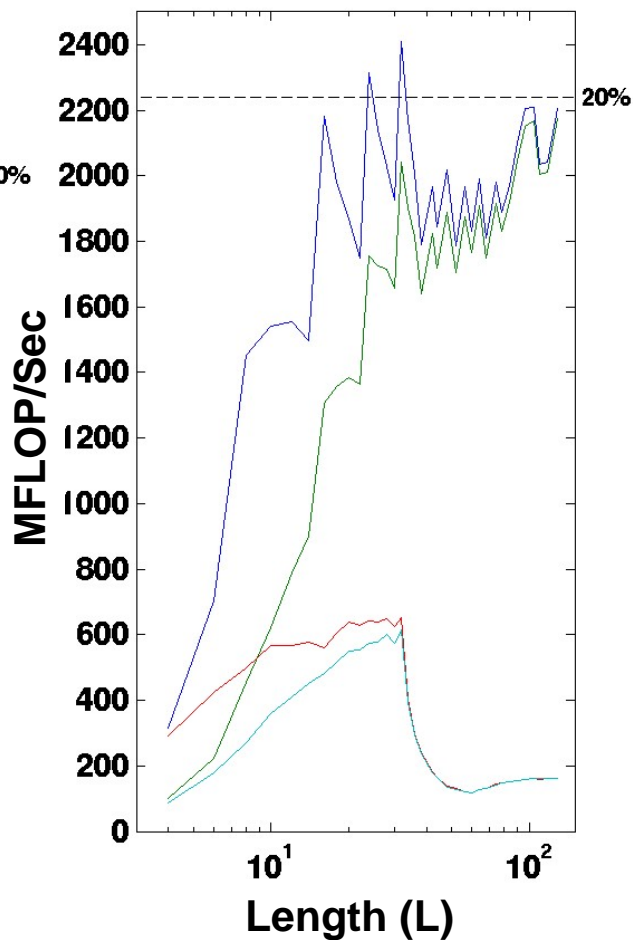


Data Set #1 - LxLxL

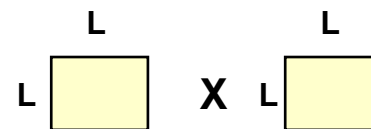
(G4 500Mhz)



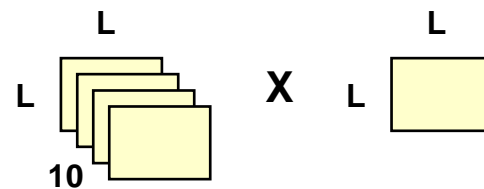
(P4 2.8Ghz)



Single Weight Multiply



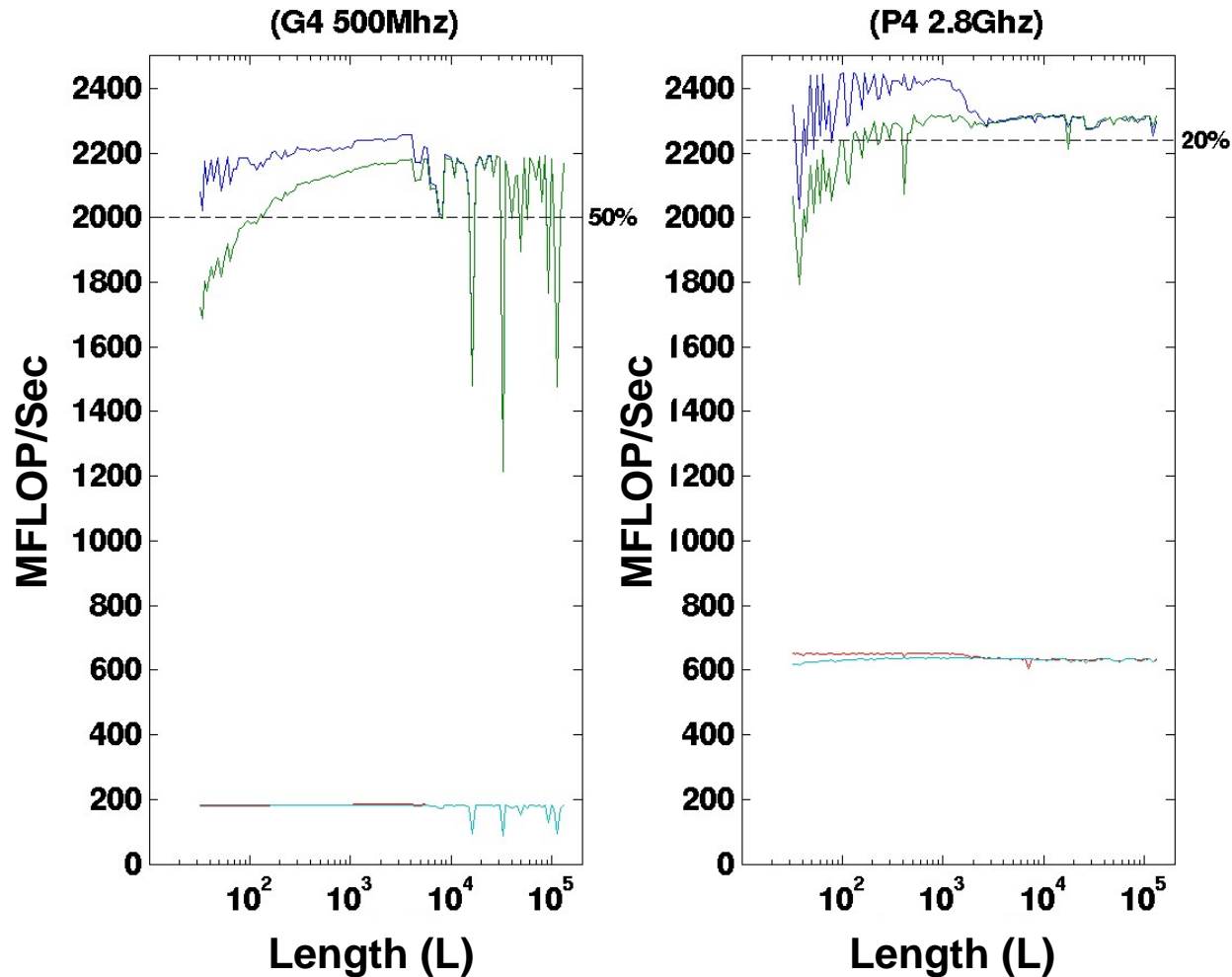
Multiple Weight Multiply



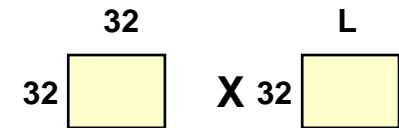
Single/wo flush —
Single/w flush —
Multiple/wo flush —
Multiple/w flush —



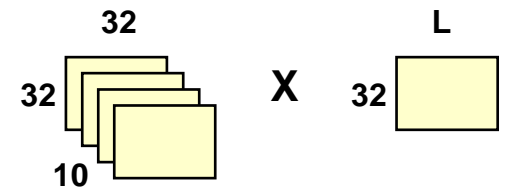
Data Set #2 – 32x32xL



Single Weight Multiply



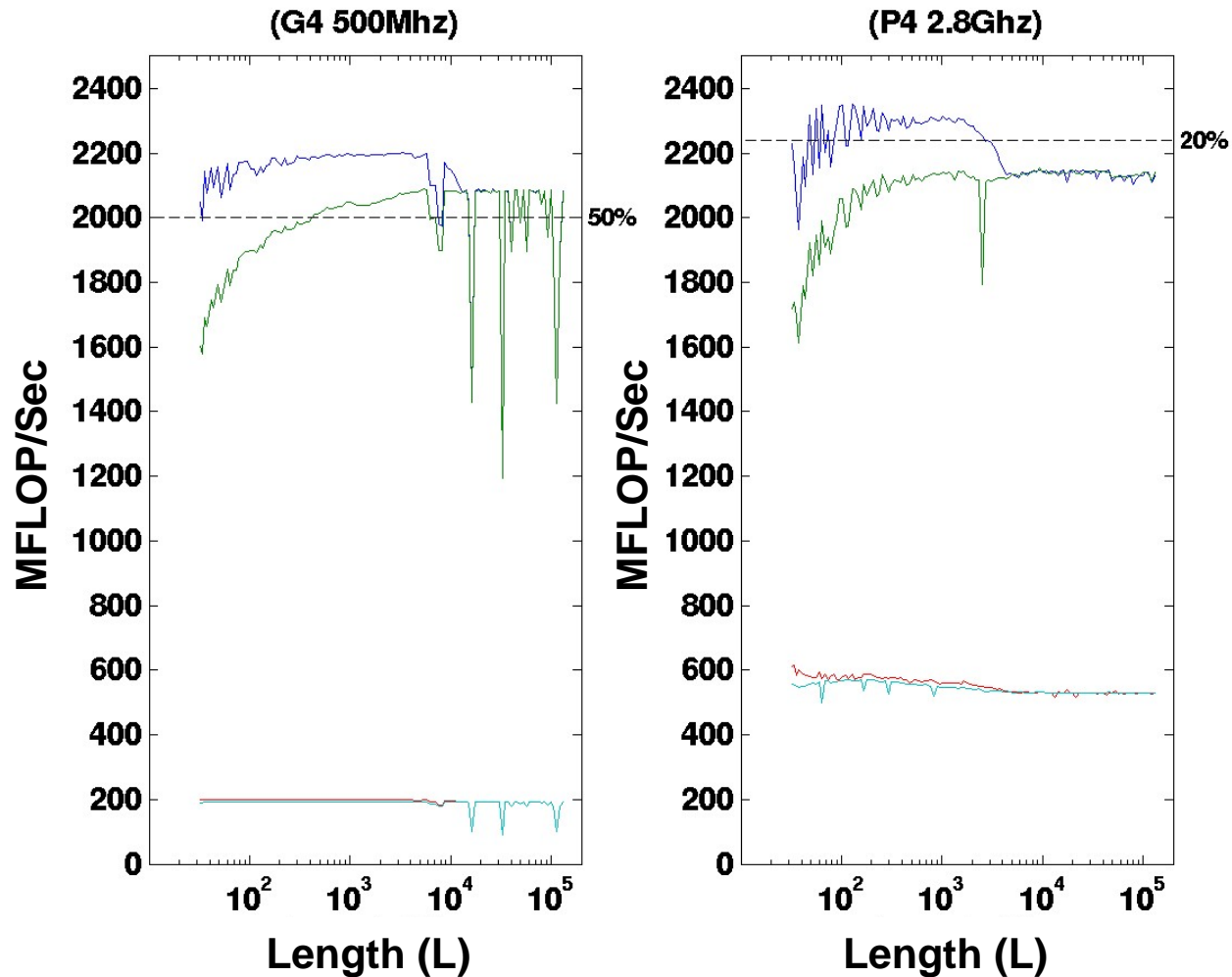
Multiple Weight Multiply



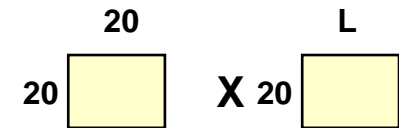
Single/wo flush
Single/w flush
Multiple/wo flush
Multiple/w flush



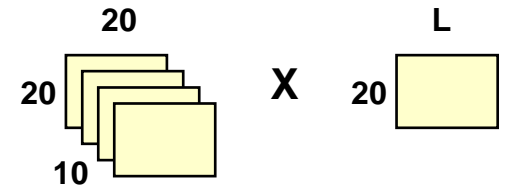
Data Set #3 – 20x20xL



Single Weight Multiply



Multiple Weight Multiply

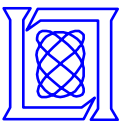


Single/wo flush ————

Single/w flush ————

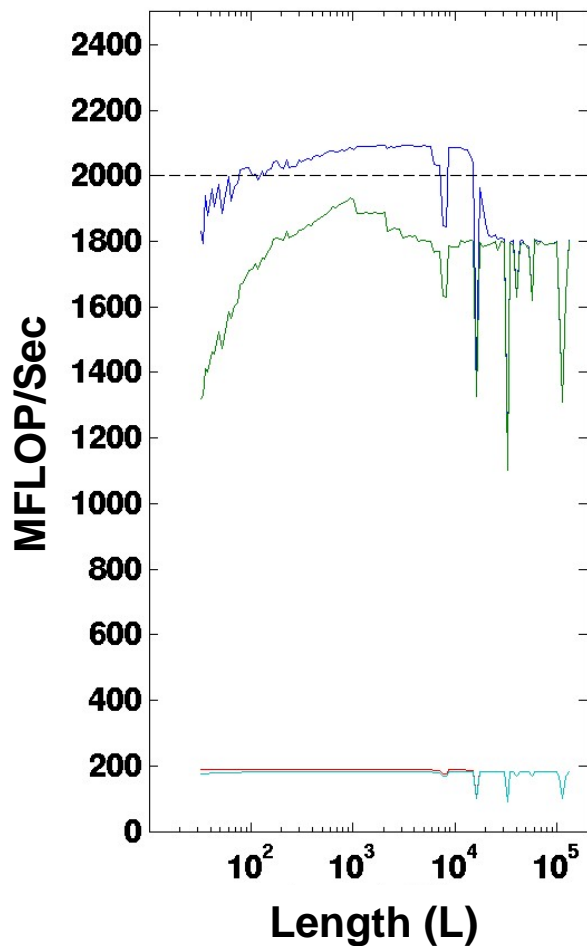
Multiple/wo flush ————

Multiple/w flush ————

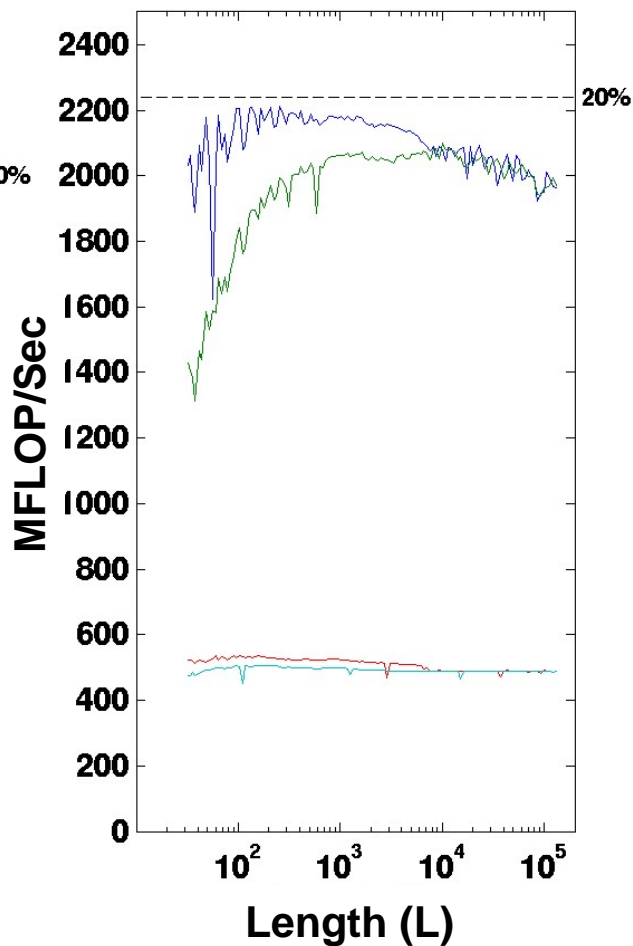


Data Set #4 – 12x12xL

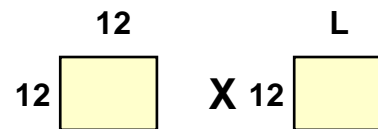
(G4 500Mhz)



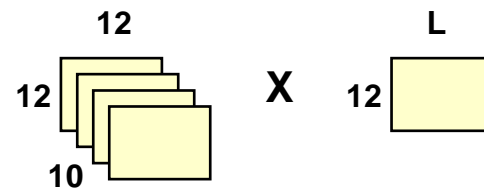
(P4 2.8Ghz)



Single Weight Multiply



Multiple Weight Multiply



Single/wo flush —————

Single/w flush —————

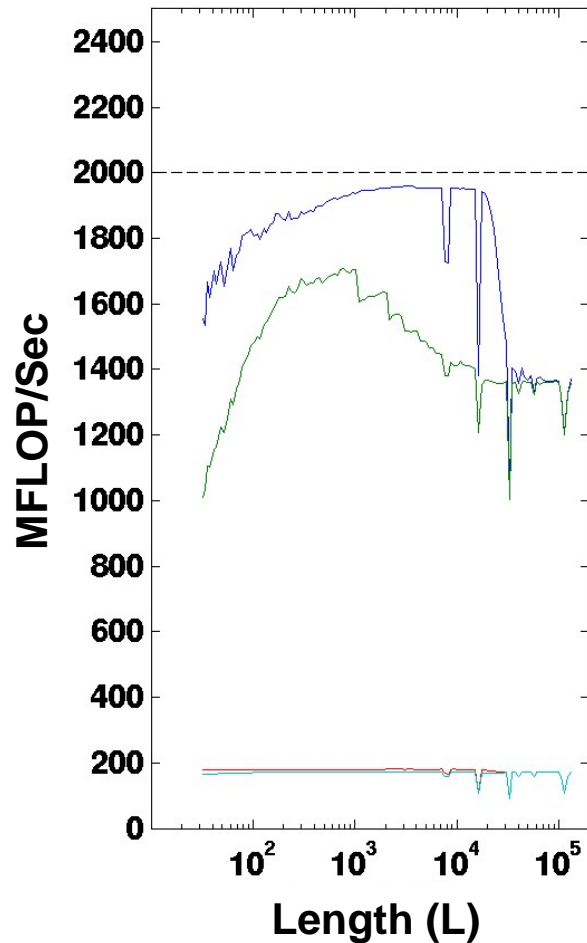
Multiple/wo flush —————

Multiple/w flush —————

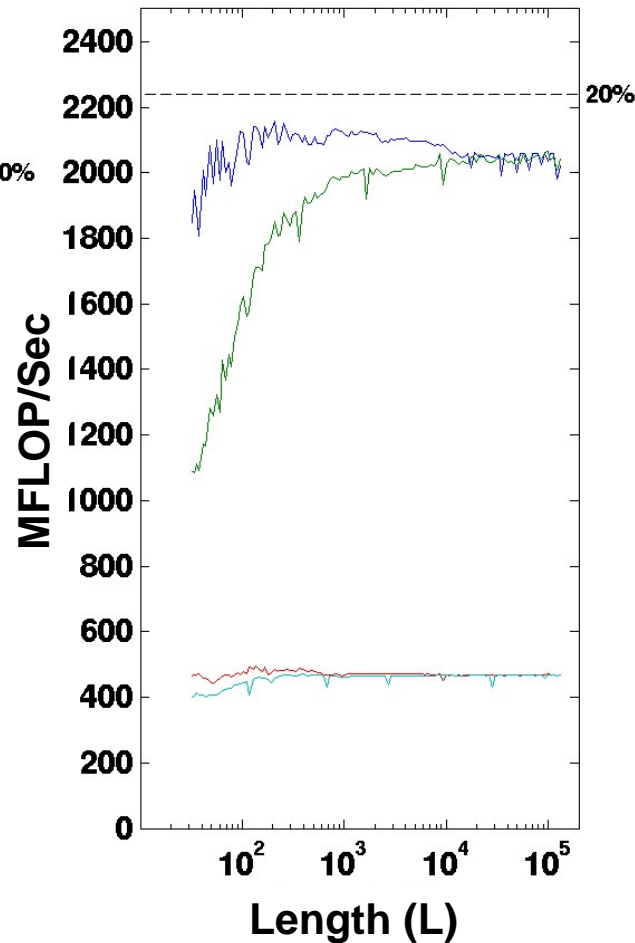


Data Set #5 – 8x8xL

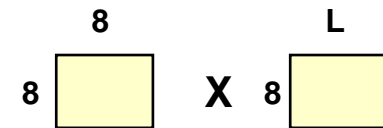
(G4 500Mhz)



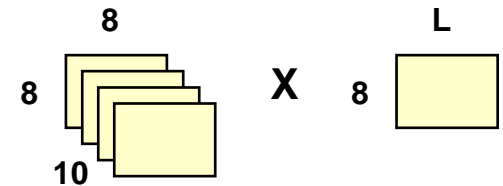
(P4 2.8Ghz)



Single Weight Multiply



Multiple Weight Multiply



Single/wo flush —
Single/w flush —
Multiple/wo flush —
Multiple/w flush —



Performance Observations

- **Data dependent processing cannot be optimized as well**
 - Branching prevents compilers from “unrolling” loops to improve pipelining
- **Data dependent processing does not allow efficient “re-use” of already loaded data**
 - Algorithms cannot make simplifying assumptions about already having the data that is needed.
- **Data dependent processing does not vectorize**
 - Using either AltiVec or SSE is very difficult since data movement patterns become data dependant
- **Higher memory bandwidth reduces cache impact**
- **Actual performance scales roughly with clock rate rather than theoretical peak performance**

**Approx 3x to 10x performance degradation,
Processing efficiency of 2-5% depending on CPU architecture**



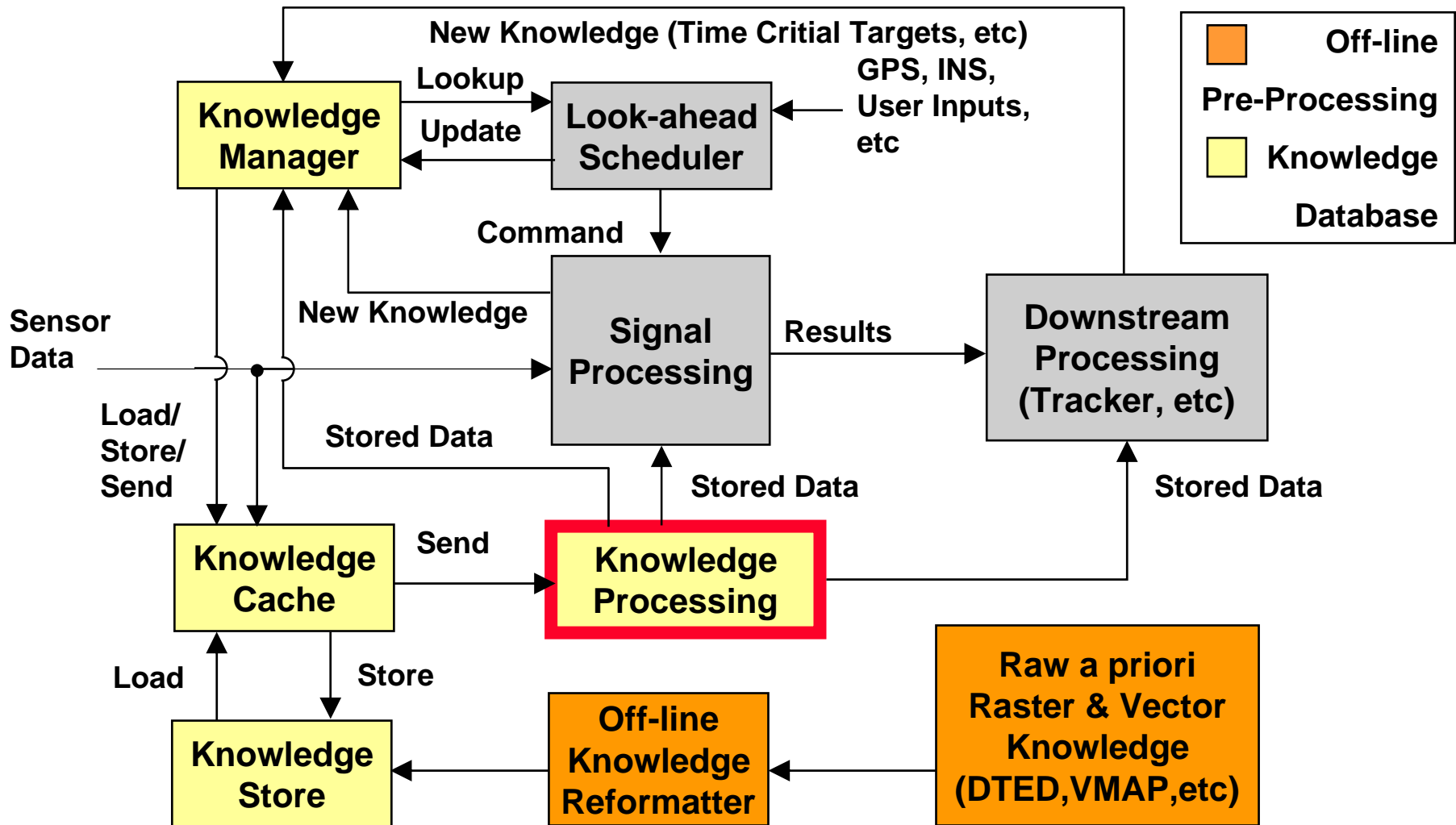
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Knowledge Database Architecture





Static Knowledge

- **Vector Data**

- Each feature represented by a set of point locations:

Points - longitude and latitude (i.e. towers, etc)

Lines - list of points, first and last points are not connected (i.e. roads, rail, etc)

Areas - list of points, first and last point are connected (i.e. forest, urban, etc)

- Standard Vector Formats

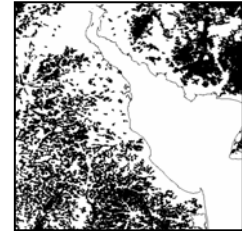
Vector Smart Map (VMAP)

- **Matrix Data**

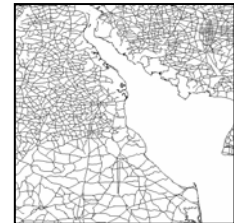
- Rectangular arrays of evenly spaced data points

- Standard Raster Formats

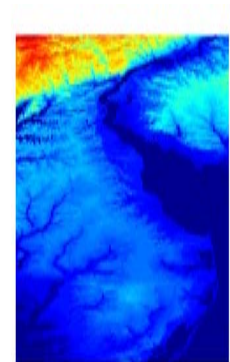
Digital Terrain Elevation Data (DTED)



Trees (area)



Roads (line)

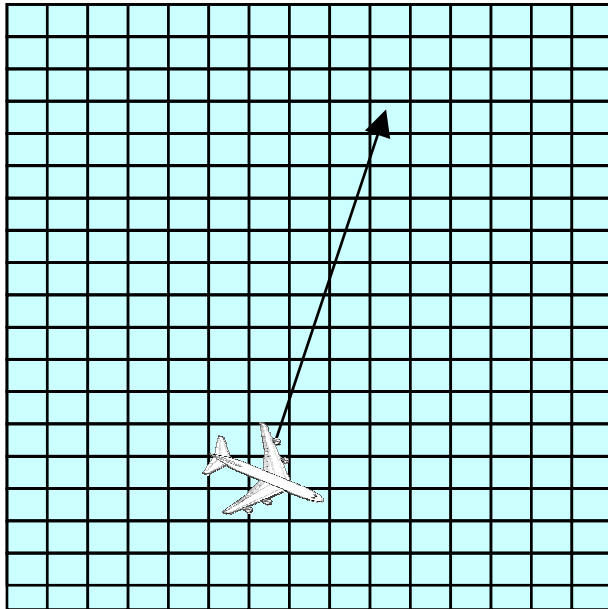


DTED

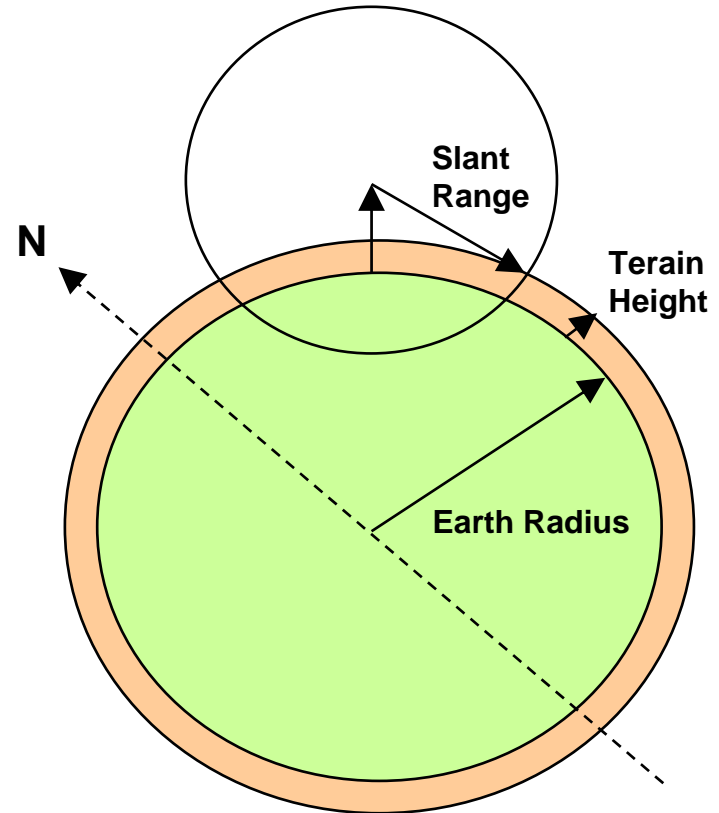


Terrain Interpolation

**Sampled Terrain Height
& Type data Data**



Geographic Position



**Converting from radar to geographic coordinates
requires iterative refinement of estimate**



Terrain Interpolation Performance Results

<u>CPU Type</u>	<u>Time per interpolation</u>	<u>Processing Rate</u>
P4 2.8	1.27uSec/interpolation	144MFlop/sec (1.2%)
G4 500	3.97uSec/interpolation	46MFlop/sec (2.3%)

- Data dependent processing does not vectorize
 - Using either AltiVec or SSE is very difficult
- Data dependent processing cannot be optimized as well
 - Compilers cannot “unroll” loops to improve pipelining
- Data dependent processing does not allow efficient “re-use” of already loaded data
 - Algorithms cannot make simplifying assumptions about already having the data that is needed

Processing efficiency of 1-3% depending on CPU architecture



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Summary

- **Observations**

- The use of knowledge processing provides a significant system performance improvement
- Compared to traditional signal processing algorithms, the implementation of knowledge enabled algorithms can result in a factor of 4 or 5 lower CPU efficiency (as low as 1%-5%)
- Next-generation systems that employ cognitive algorithms are likely to have similar performance issues

- **Important Research Directions**

- Heterogeneous processors (i.e. a mix of COTS CPUs, FPGAs, GPUs, etc) can improve efficiency by better matching hardware to the individual problems being solved. For what class of systems is the current technology adequate?
- Are emerging architectures for cognitive information processing needed (e.g. Polymorphous Computing Architecture – PCA, Application Specific Instruction set Processors - ASIPs)?